Safeguards Approaches for Light Water Reactors

LANL Safeguards Systems Course – 2009

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Let Us Define What is Safeguards

INFCIRC 153 Para. 28: The Safeguards Technical Objective

Comprehensive Safeguards Agreement (CSA)
"Traditional Safeguards"

INFCIRC/153 Para. 28: The Safeguards Technical Objective

… the objective of safeguards is the *timely detection* of *diversion* of *significant quantities* of *nuclear material* from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and *deterrence of such diversion* by the *risk of early detection*…

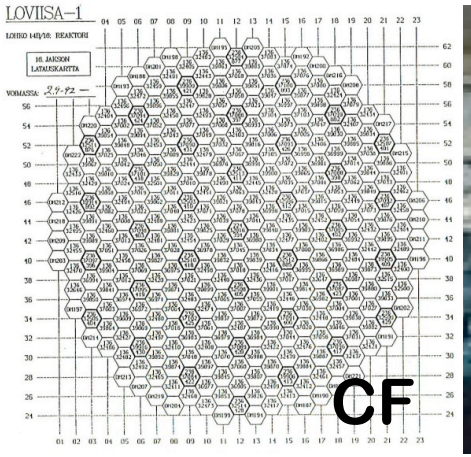
NOTE:

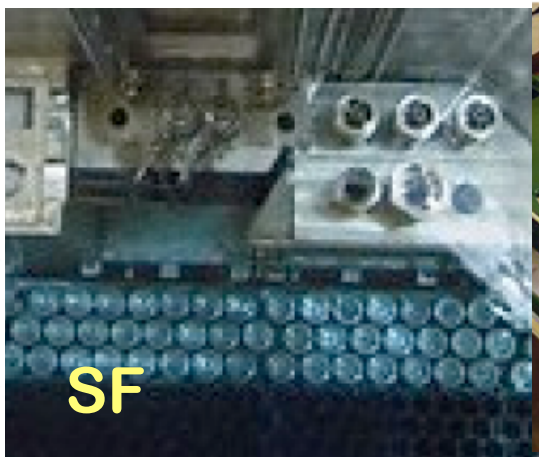
- **Timeliness**
- **Significant Quantities**
- **Deterrence by Risk of Early Detection**

Timeliness and Goal Quantities

Relevant to LWR Safeguards (without Fresh MOX)

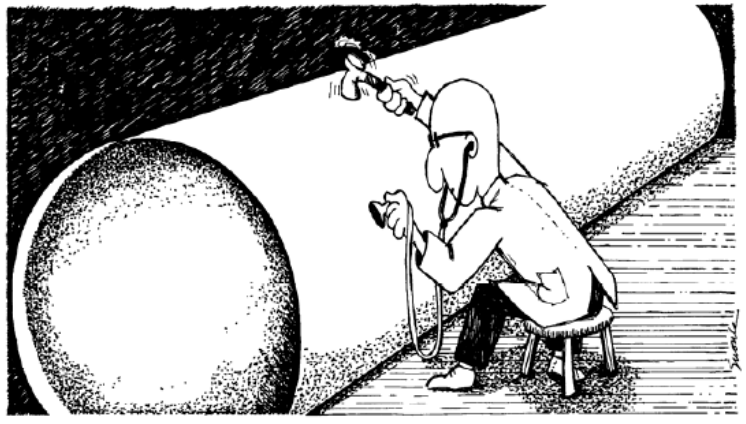
MATERIAL CATEGORY	EXAMPLE	AMOUNT OF SQ	TIMELINESS GOAL
Irradiated Direct-Use	Core Fuel (CF), Spent Fuel (SF)	Pu = 8 kg	3 months
Unirradiated Indirect-Use	LEU Fresh Fuel (FF) Core Fuel (CF) Spent Fuel (SF)	U-235 = 75 kg	1 year





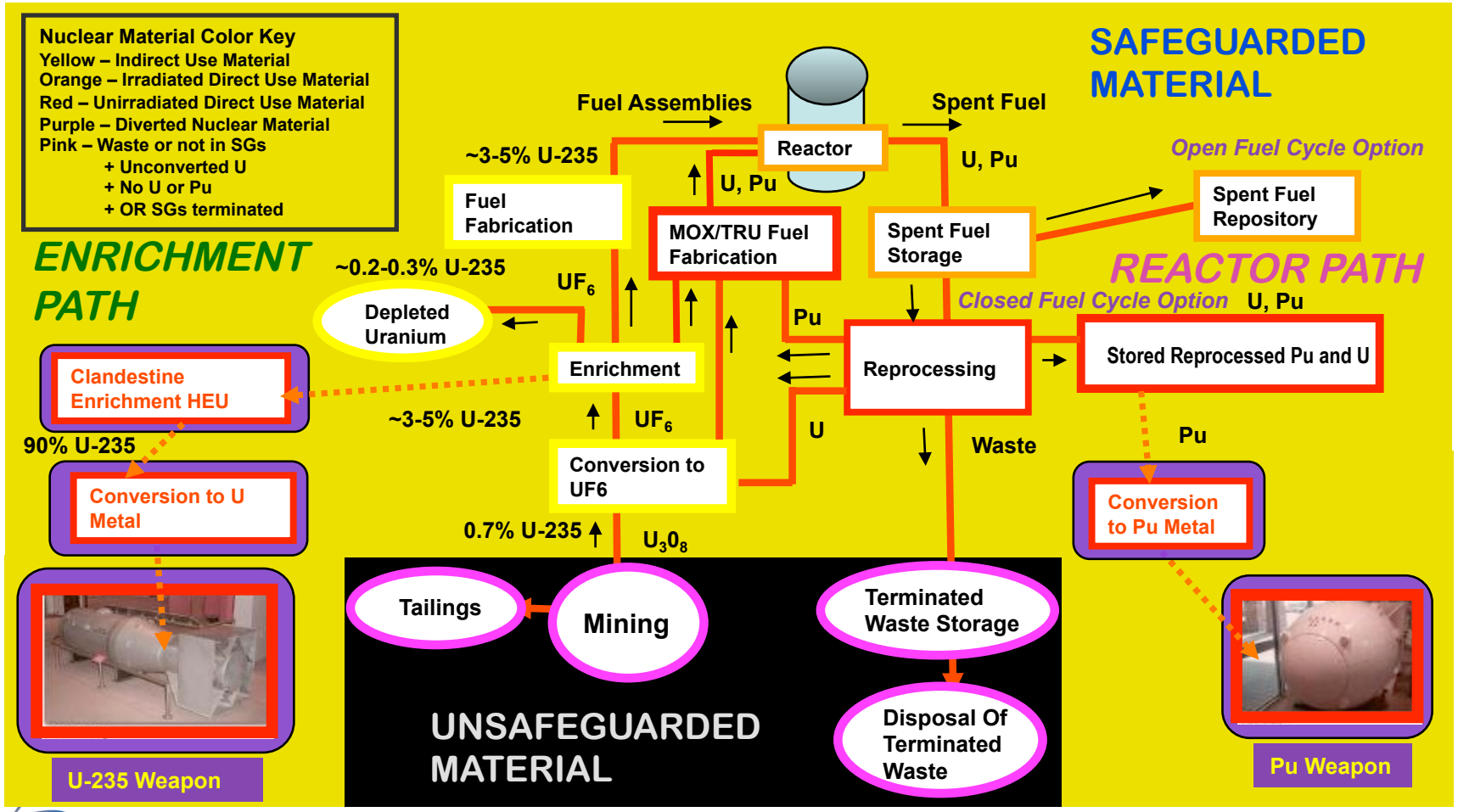
IAEA Accountancy Verification Methods
LWR Application

- Three levels of defects to detect with NDA Instruments:
  - ***Gross defect***
  - ***Partial defect***
  - ***Bias defect***
- Examples in LWRs:
  - ***Gross defect***
    - **Assembly missing/dummy sub**
  - ***Partial defect***
    - **>50% of pins missing from SFA**
  - ***Bias defect***
    - **Not Applicable in Present LWR SG**
    - **Example in future could be 1-2 pins missing from SFA**



Nuclear Fuel Cycle – Proliferation Aspects

Reactors – Plutonium Path



LWR Categories

- **Type 1 - Reactor hall includes spent fuel pool**
  - VVER 440 (Loviisa 1-2, Mochovce 1-2)
  - VVER 1000 (**Khmelnitsky 1-2**)
  - BWRs with SF pool in containment (TVO 1-2)
  - PWRs with SF pool in containment (Biblis 1-2)

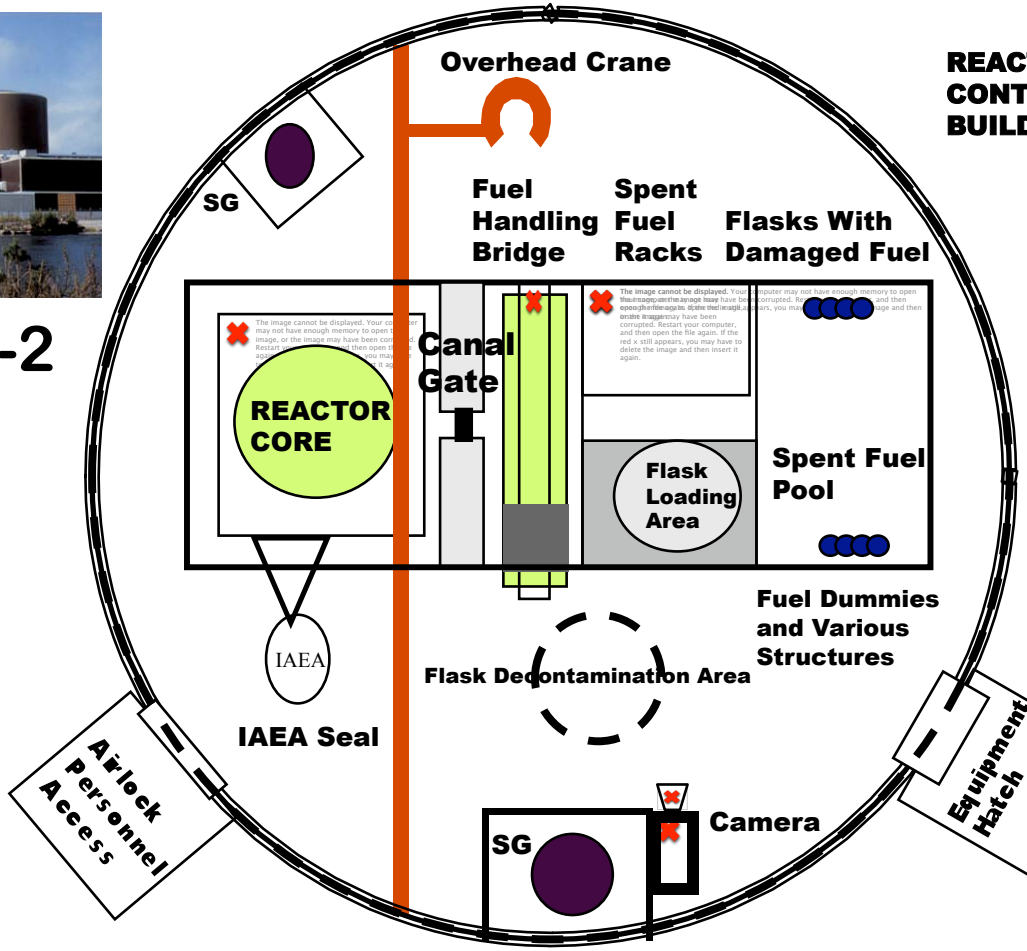
Khmelnitsky 1-2
Ukraine

- **Type 2 - Spent fuel pool outside of reactor hall**
  - PWRs with SF pool in separate building (**Krško**)
  - BWRs with SF pool in separate building (Liebstadt)

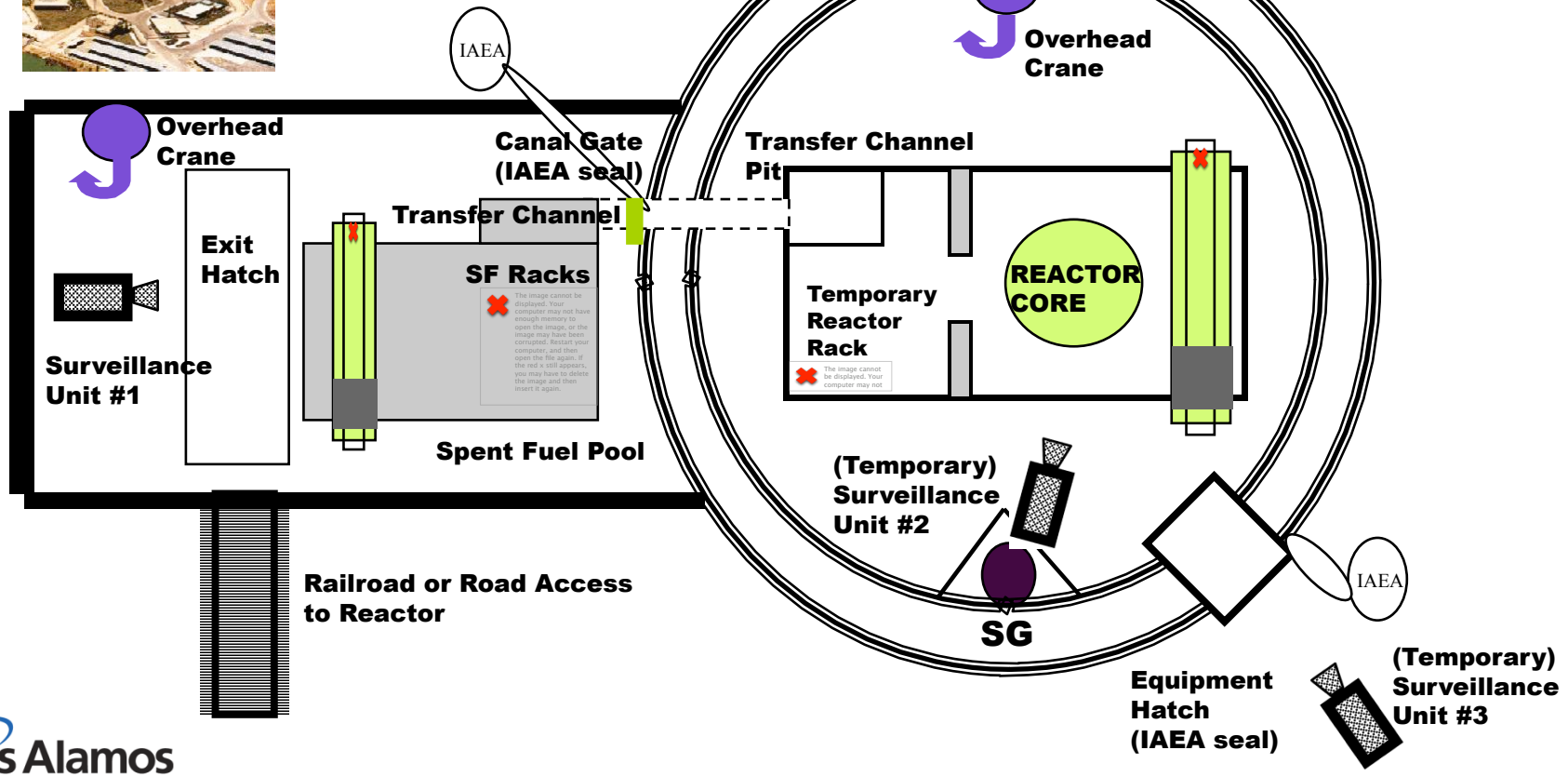
Krško
Slovenia

LWR Layout - Type I Reactor Design

Loviisa 1-2
Finland



LWR Layout - Type II Reactor Design



Containment and Surveillance (C/S)

Surveillance Used in LWRs

- **Reactor Hall**
  - Core Fuel During Refueling: Type 2 LWR
  - Core Fuel / Spent Fuel / Casks Core Fuel: Type 1 LWR
- **Separate SF Pool**
  - Spent Fuel Pool and/or Exit Routes
- **Exits (Large enough to move SF cask through)**
  - Containment Hatch (Westinghouse PWRs)
  - Containment Hatch (WWER 1000)
  - Loading Bay in SF Pool (Type 2 LWR)

DCM-14 Digital Surveillance Camera

Containment - Sealing

- **Surveillance Instruments (Cameras, Surveillance Cabinets)**
- **Reactor Hall**
  - Vessel Missile Shield (VVER 440)
  - Other means to immobilize Core Fuel

- **SF Pool**
  - Spent Fuel Racks and Pool Covers - immobilization of SF
  - Loaded SF casks ready for shipment
  - Re-fueling crane
    - Temporary measure while inspectors are in town

- **Exit Pathways**
  - SF Pool canal gate and Exit hatches

Physical inventory verification (PIV)

- **PIV - yearly with the period between PIVs not to exceed 14 months**
  - Performed when core is refueled or opened
  - If core not refueled or opened - PIV done with closed core
  - Multiple cores - (VVER 440 - twin reactor per facility)
    - Do PIV during one of the core openings
  - Post PIV period should not exceed 3 months

PIV- Verify Fresh Fuel

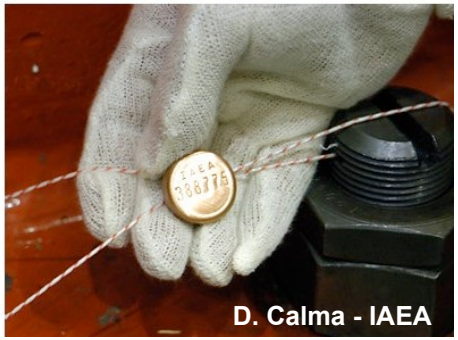
- **Fresh Fuel (FF) (verify prior to insertion in pool)**
  - Item counted
  - Verified for gross defects *or* by serial number ID (by random sampling)
    - NDA (CdTe - MMCC)
    - NDA (HM-5)

Gross Defects Test - MMCC - Portable Multi-channel Analyser + CdTe Detector

- MMCC Detects 186 keV U-235 γ peak in γ spectrum
  - CdTe detector
    - inserted into fuel assembly
    - gamma spectrum measured
  - Definitive gross defect measurement of
    - Fresh LEU fuel
    - U-235 **is** or **is not** present

PIV - Core Fuel Verification

- **Open core** –
  - Assemblies *item counted* and
  - *Acceptable C/S maintained* either on
    - Open core or on removal routes

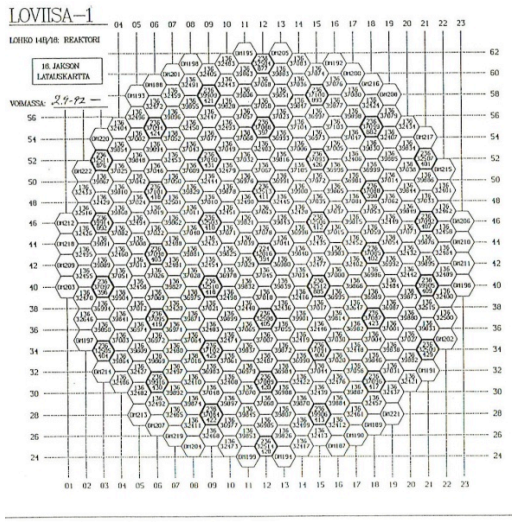


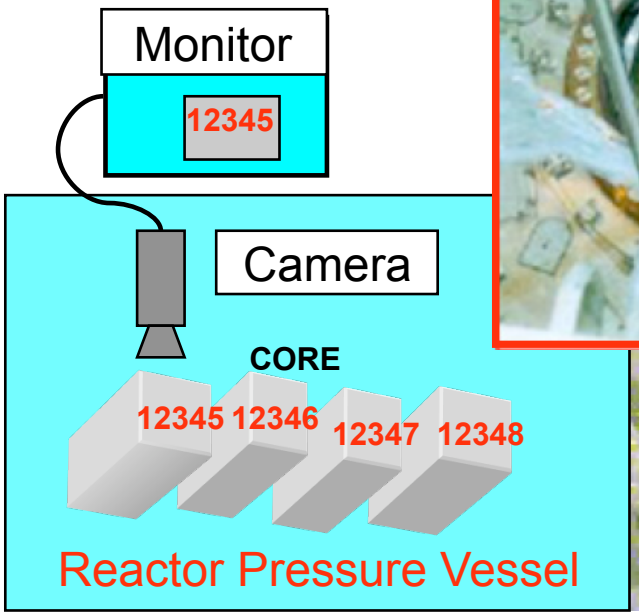
- **Discharged**
  - Core is discharged to SF Pool
  - Verify along with SF
  - *Acceptable C/S maintained* either on
    - Open core or on removal routes

- **Closed cores**
  - If under C/S - the C/S system is evaluated

PIV - Verifying Core Fuel with UWCC

- **Verify new core configuration**
- **The TV camera pans across the fuel**
  - Serial numbers are verified
  - The total number of fuel assemblies counted
  - Compared to the operator's declaration

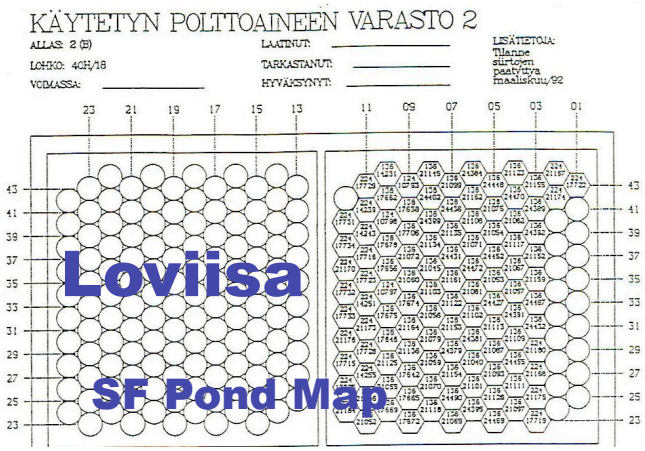


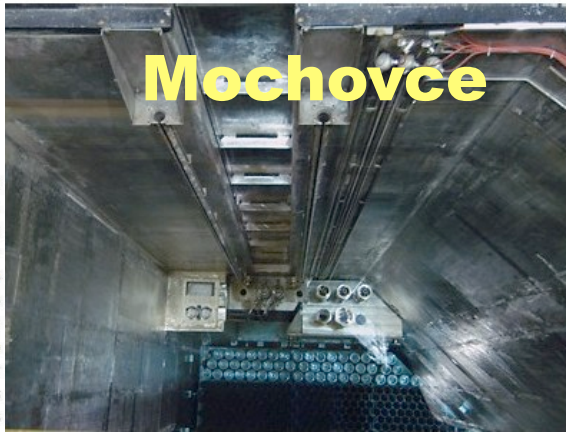


PIV - Verify Spent Fuel

Spent Fuel (SF) Pools verified 100% for Gross Defects

- **Easier to verify all items then to select specific items in pool**
- **ICVD – factors for successful viewing of Cerenkov glow**
  - Water quality
  - Fuel assembly burn-up
  - Residence time in pool by SF
- **With failure of ICVD - use of SFAT or similar method is attempted**
  - Only Gross Defect tool – no credible Partial Defect tool in IAEA SG toolbox
- **IAEA has new intense interest in NON-FUEL items in SF pool**
- **C/S Evaluated**



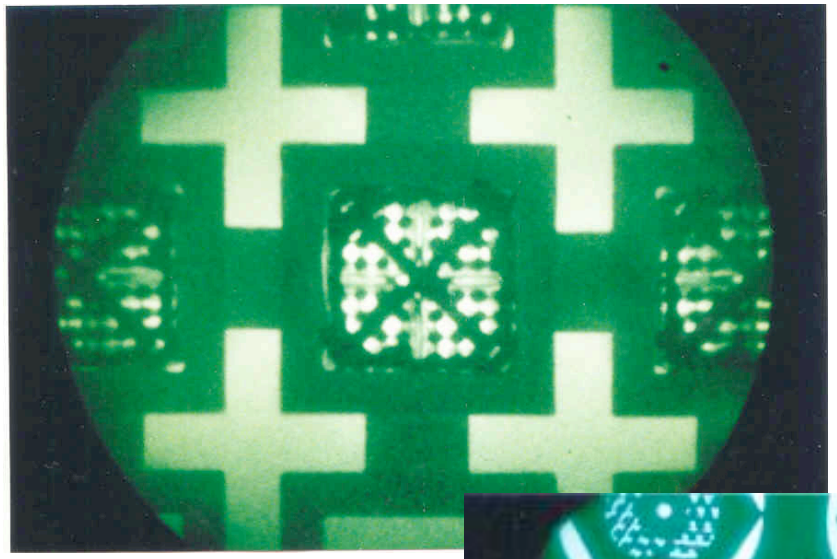


ICVD - Improved Cerenkov Viewing Device Detects Cerenkov Glow from SF

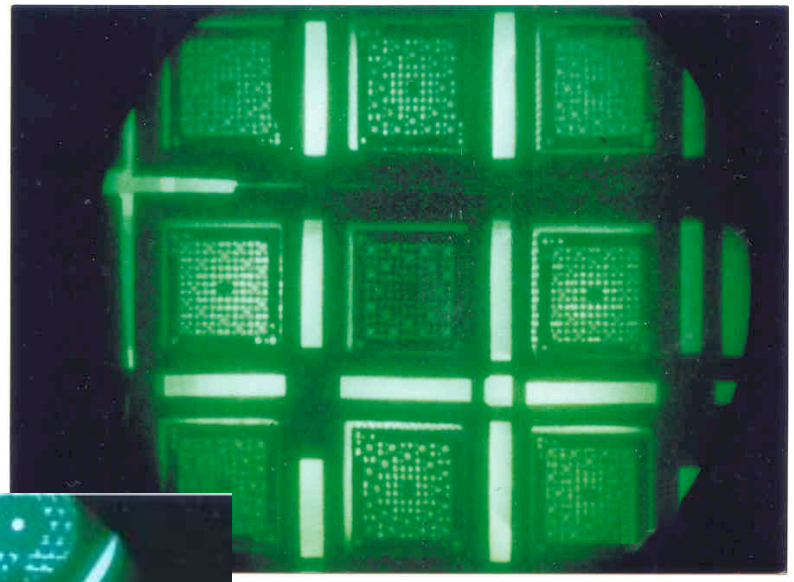
- **ICVD verifies Spent Fuel (SF)**
  - Spent Fuel (SF) Pools
  - SF in Baskets and/or Casks prior to shipment
- **ICVD verifies Core Fuel (CF)**
  - CF during refueling to recover from ANOMALY (EXAMPLE:
    = Loss of CofK of Core
    = Recover next PIV during refueling

ICVD
Price $50,000

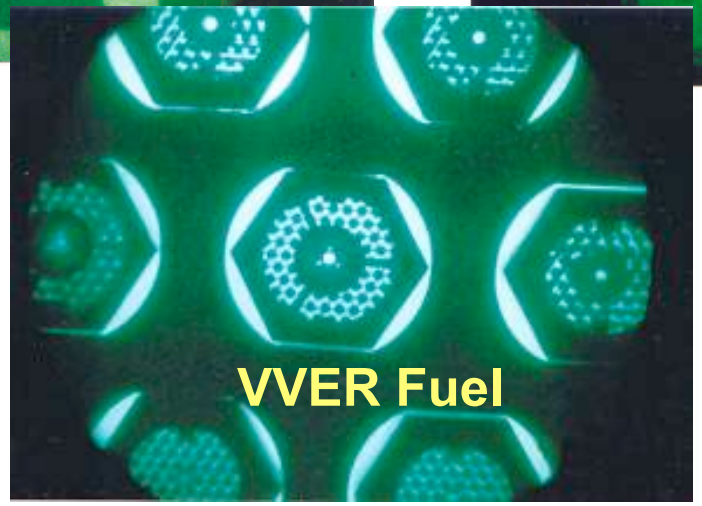
ICVD – Various LWR Fuel Design Cerenkov Images



BWR Fuel

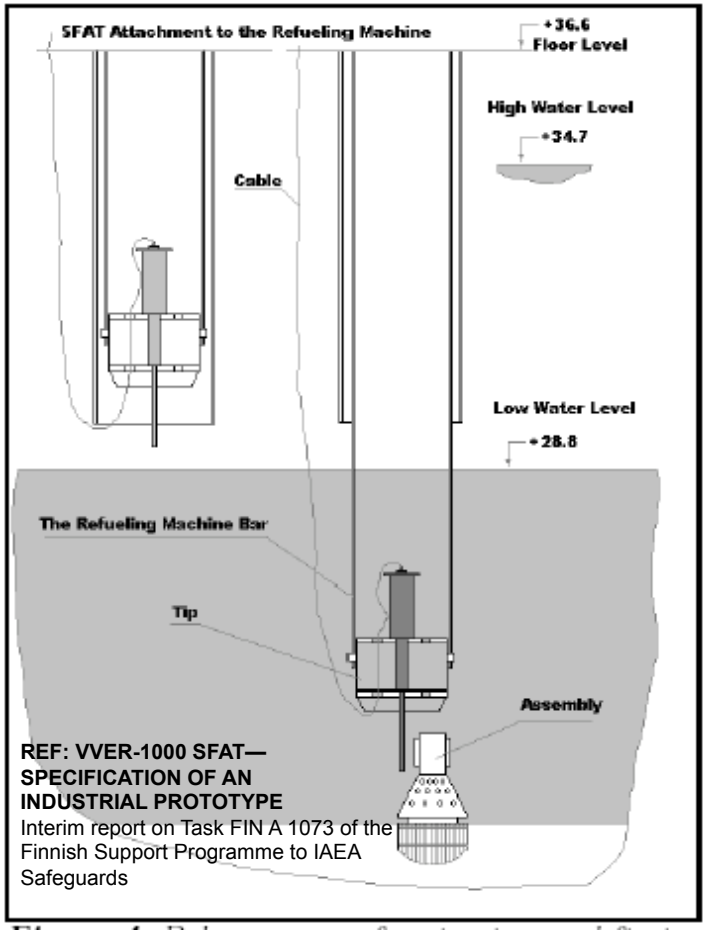


PWR Fuel



SFAT - Spent Fuel Attribute Tester

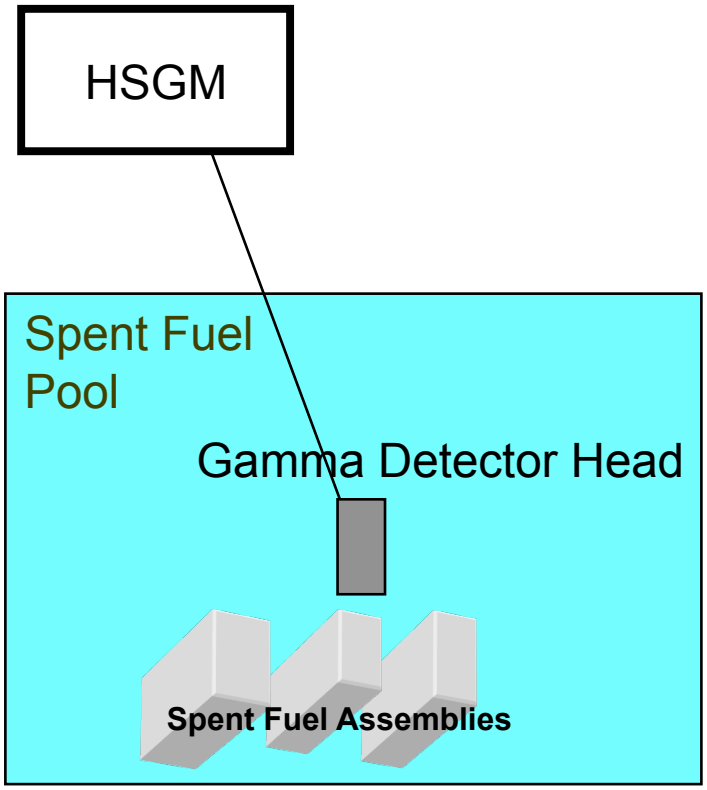
- **Detects Cs-137 660 keV gamma peak in SF gamma spectrum characteristic of fission products**
- **Used to verify**
  - SF Pool fuel too old (radiation decaying away) or fuel with low burn-up (few fission products)
  - SF items that may be dummy elements, skeleton assemblies, empty containers - by lack of a Cs-137 peak



REF: VVER-1000 SFAT—SPECIFICATION OF AN INDUSTRIAL PROTOTYPE
Interim report on Task FIN A 1073 of the Finnish Support Programme to IAEA Safeguards

HSGM - High Sensitivity Gamma Monitor Detects Gamma Radiation from SF

- **Gross defect measurement**
- **HSGM and CPMU**
  - **Crude measurements**
  - **Not very definitive or quantitative**
- **Can give higher measurements from empty container for damaged SF as from full container**
- **Dummy element can be irradiated and give off gammas**



Confirm Absence of Unreported Production of Plutonium

- **METHODS:**
  - PERFORM
    - Analysis of reactor shows it could not produce 1 SQ of unrecorded Pu per year
  - OR
    - C/S on RPV to confirm RPV was closed AND
    - C/S on open RPV to confirm that 1 SQ was not removed from the core AND
    - Empty RPV - confirm CF is in SF and none removed
  - AND
    - C/S acceptable on SF pool OR
    - Verify SF Pool after refueling with NDA where appropriate

- **ISSUES with Pu production**
  - Operator's calculations of burn-up will have errors
  - Not problem with SF going to SF repository
  - Reprocessing!!! - SRD at reprocessing plant – bigger issue in GNEP

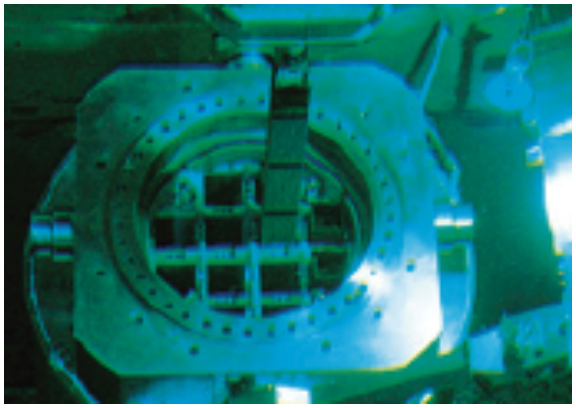
Verification of Domestic and Int'l Transfers

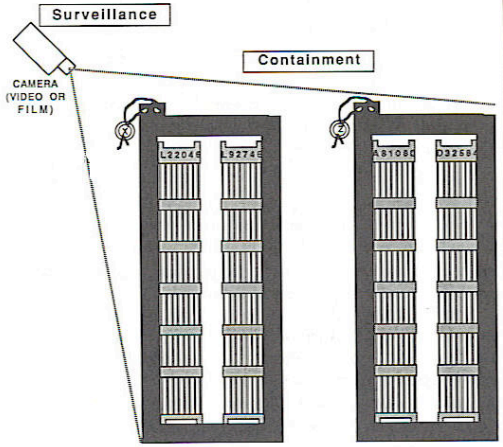
Spent Fuel - To Difficult-to-Access

- **Transfers of SF**
- **Containers for long-term storage under SG but difficult-to-access**
- **Verification activities to insure CofK of material**
  - Item I.D. (UWTV to I.D. S/N of SF)
  - NDA (high detection probability for gross and partial defects - usually gross defects with ICVD)
  - Under dual C/S

    Example: COBRA seal and metal seal

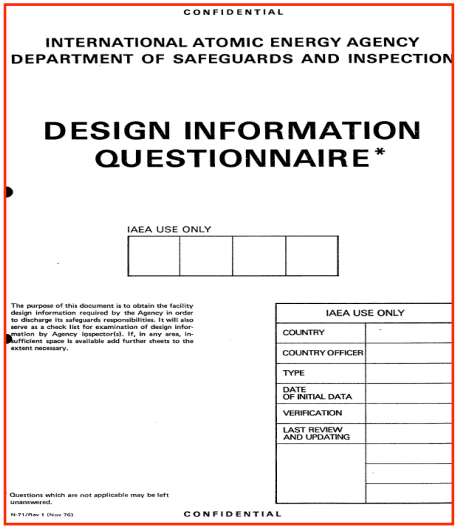
    Surveillance and metal seal





Design Information Verification (DIV)

- Design info provided to Agency by the State
  - Examined *and* Verified
- Once a year re-examined
- Periodic verification of design information
  - Confirm continued validity of info
  - DIV includes
    - Taking of environmental samples



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INTERNATIONAL ATOMIC ENERGY AGENCY
DEPARTMENT OF SAFEGUARDS AND INSPECTION

DESIGN INFORMATION QUESTIONNAIRE*

IAEA USE ONLY

The purpose of this document is to obtain the facility design information required by the Agency in order to discharge its safeguards responsibilities. It will also serve as a check list for examination of design information by Agency inspector(s). If, in any area, insufficient space is available add further sheets to the extent necessary.

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COUNTRY OFFICER	
TYPE	
DATE OF INITIAL DATA	
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Questions which are not applicable may be left unanswered.

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Typical Agency Yearly Schedule at LWR

- 3 Interim Inventory Inspections (IIV) and PIV scheduled
  - Verify CF and SF - 4 x per year – timeliness goals
- Special inspections for transfer of SF in casks
  - Verify SF as placed in cask
  - Follow with C/S to maintain CofK

- Pre PIV
  - Verify FF
  - Detach seals on reactor or transfer paths
  - Install temporary surveillance to reactor
- Post PIV
  - Attach seals on transfer paths (canal gate, etc,)

Summary - LWR Safeguards Goal

- **Control of Spent Fuel - Source of Pu**
- **Control of SF pool items - Targets for Pu production**
- **Control of LEU fuel - LEU for enrichment / Pu production in reactor**
- **Control of Transfers - SF that may be reprocessed for Pu**
- **Fuel Cycle Concerns**
  - State Level Approach – Fuel Cycle in a State
  - AP in Force
  - Broader Conclusion / Integrated Safeguards
  - Sensitive Technologies
    - Reprocessing
    - Enrichment